Impact of climate change on river hydrology and ecology: case study for interdisciplinary policy oriented research

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Abstract The impact of climate change on river hydrology and ecology is a subject that receives increasing attention and has strong implication for hydrological, ecological, economic and social policy. Because climate change affects such wide variety of disciplines, pursuing research in this field requires an interdisciplinary approach. There is a need to simultaneously understand and project the climate change, and to project and effectively deal with its impacts on the present and future aquatic ecosystem, which presents a great challenge to the global research community. This paper summarizes the experiences obtained by a Belgian research project in which key experts from climatological, hydrological and ecological research communities, as well as water managers and policy makers, are brought together, in order to improve the decision making regarding the impact of climate change on aquatic and floodplain ecosystems. The project focuses on a case study "Grote Nete", which allow us to adapt these relevant issues, while focusing on the combined information from climate projections. Interdisciplinary linkages and feedback mechanisms in the interfacing between climatology and hydrology, between hydrology and ecology and with water managers and policy makers are discussed, as well as the current knowledge and interfacing gaps and related challenges.

Keywords climate change; aquatic ecosystems; rainfall-runoff; river modelling

INTRODUCTION AND BACKGROUND INFORMATION

The impact of climate change on river hydrology and ecology is a subject that receives increasing attention and has strong implication for hydrological, ecological, economic and social policy. Only a modest change in the average of temperature or precipitation may imply changes in the statistical distribution of extremes and its consequences on the ecosystem (e.g. IPCC 2007, EEA 2008). One of the variables of main interest is the chemical river water quality. It is a function of the chemical load applied to the river, the water temperature, and the volume of flow. Changes in the intensity, duration and frequency of rainfall events can alter unpaved and paved runoff contributions, nutrient leaching, occurrence of sewage overflow events, dilution of pollution, etc. Therefore changes in river flows may alter the oxygen levels, organic pollutant and nutrient loads which are primary factors for species composition and biodiversity in aquatic ecosystems (especially fish populations). Furthermore, altered flood regimes by changes in river flow regimes can also have impacts on the species composition and biodiversity of river valley and floodplain habitats. Consequently, research is needed to study the impacts of flood scenarios (frequency, duration, water height and season) on floodplain vegetation communities (habitats) and aquatic ecosystems.

Because climate change affects such wide variety of disciplines, pursuing research in this field requires an interdisciplinary approach. This need to simultaneously understand and project the climate change, and to project and effectively deal with its impacts on the present and future aquatic ecosystem, presents a great challenge to the global research community. However, when integrating climatologic, hydrologic and ecologic information a lot of discussions emerge regarding the adequate space and time scales, use of indicators, ways of modelling these indicators, limitations of modelling approaches, uncertainties involved, climate scenarios and adaptation measures to be simulated, etc. There is a clear gap between what climatologists offer to the impact research community (in terms of variables and scales), and the starting point of the hydrological impact research, as well as the variables and demands by the ecological impact researchers. Moreover, while it is important to understand sources and magnitudes of climate change and impact uncertainties, there is also a need to understand how and in what form policy makers can deal with these uncertainties. The question arising here is how to address in both communication and decision making the uncertainties associated with regional climate change projections and related impact quantifications.

This paper summarizes the experiences obtained by a Belgian research project in which key experts from climatologic, hydrological and ecological research communities, as well as water managers and policy makers, are brought together, in order to improve the decision making regarding the impact of climate change on aquatic and floodplain ecosystems. The project aims to enhance the communication and mutual understanding of offers and demands between the disciplines involved. This was done with focus on a specific river basin in Belgium, combining information from climate projections, changes in flow regimes, associated water quality, and ecology/biodiversity, with the final aim to allow far better projections of habitat quality and diversity. Specific objectives were to:

1. discuss relevant research issues in an open, interdisciplinary team to take stock of what is known in pertinent fields and identify the connections between them;
2. foster communication across the disciplinary and academic lines that divide us so as to push forward the research to an efficient and fruitful ways;
3. based on the case study specific focus, delineate the state-of-the-art from which we then can develop both a research and action agenda within the context of climate change in Belgium, with a view on assessing other impacted sectors;
4. assess the impact of climate change on the aquatic river valley and floodplains biodiversity;
5. integrate the technical outcomes in river basin management policy and plans.

METHODOLOGY

In order to meet the main objectives of enhancing communication across the climatological, hydrological and ecological disciplines, of identifying the offers and demands in terms of variables, time and space scales and uncertainties/limitations, of communicating the climate and climate impact science to managers and policy makers, specific focus is given to a case-study. The basin of the Grote Nete river in Belgium (Fig. 1) is selected because ecological conservation is of primary importance in the basin management and planning. Like many European catchments, the Grote Nete basin has been experiencing an increase in extreme hydrological events. In addition, extreme rainfall events by both duration and intensity have been observed more frequently during the last decade. Wide alluvial plains with shallow groundwater and distributed seepage can be found in the downstream parts of the basin. The boundaries of the recent floods (09-1998, 12-1999, 02-2002 and 01-2003) extended to a large part beyond the natural alluvium of the river.

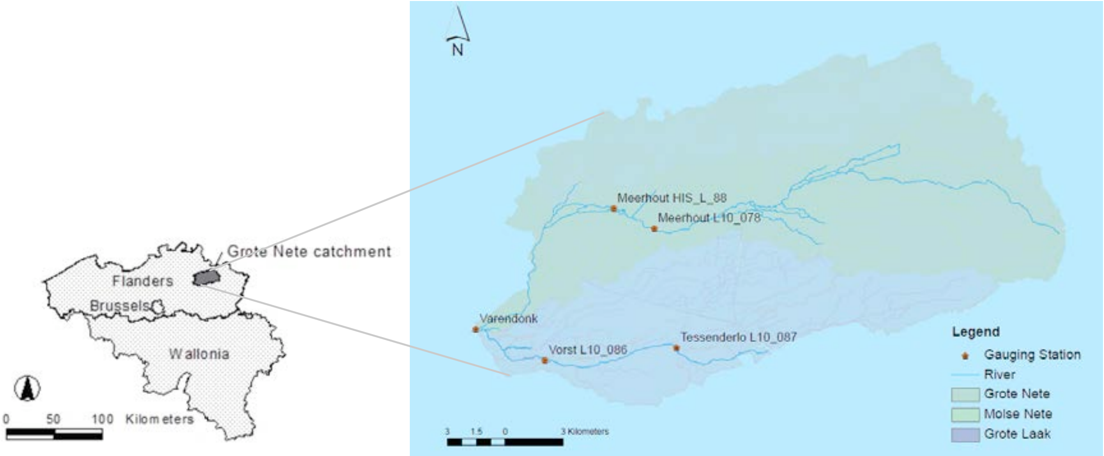


Fig. 1 Location of the Grote Nete basin in Belgium (left); modelled catchments and river network (right).

Investigation of the impacts of climatic changes on the biodiversity of aquatic and terrestrial ecosystems in the Grote Nete basin requires the steps highlighted in Fig. 2. It involves four main steps: climate projections (provided by the climatologic research community), hydro-chemical research dealing with changes in water flow regimes and water quality (hydrological research community), ecological aspects where the ecological impacts of these changes are studied (ecological research community), and translation of the results for the policy makers (i.e. river basin management and planning by the Flemish Environment Agency and the Province of Antwerp).

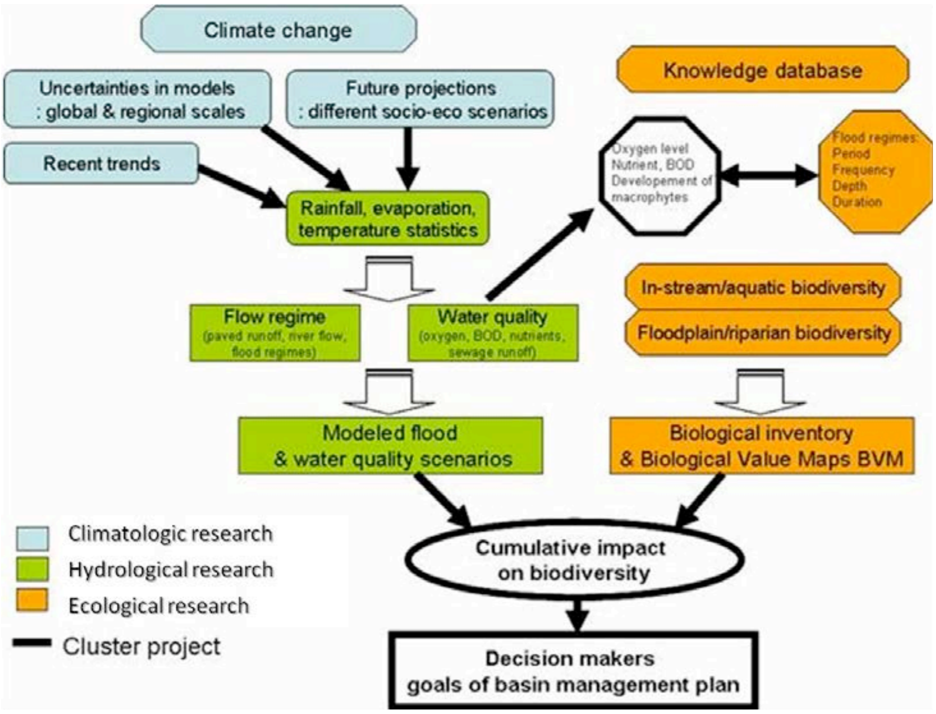


Fig. 2 Framework for assessing the impacts of climate changes on the biodiversity of aquatic and terrestrial ecosystems in the Grote Nete basin. Colour boxes indicate steps or processes that are traditionally covered in a disciplinary way by climatologic, hydrological and ecological research communities. Bold arrows indicate the interfacing problems that are addressed in this paper.

The methodology followed consists of four main steps.

1. Organization of a series of workshops bringing together all sectors (climatologists, hydrologists / water engineers, biologists / ecologists and policy makers). Also hydrometeorologists, sociologists and economists are involved and put their expertises in the general discussion around climate change and environmental friendly adaptation measures with specific focus on the case study.
2. State-of-the-art reports are developed as outcomes of the workshops. These reports reflect the results of the interdisciplinary cooperation and solutions bridging the gaps after interdisciplinary communication. They also describe the framework for translating the scientific results on climate change and environmental impacts to the needs of policy makers.
3. Technical working groups are set that aim at bridging the gaps between:
   - Climatological and statistical hydrology communities on the development of climate change scenarios and their uncertainties.
   - Ecological and hydrological communities on the climate change propagations to flow regimes, chemical quality and biodiversity.
4. Involvement of the regional water authorities in the workshops and separate science-policy interfacing meetings in order to promote integration of the technical outcomes in the basin management policy and planning.

CASE STUDY RESULTS

The case-study outcomes of the technical working groups are hereafter summarized, followed by the formulation of research questions left and the process recommended for the integration of these technical outcomes in the basin management policy and planning and for the development of adaptation strategies.

Development of climate change scenarios for rainfall, temperature and potential evapotranspiration, in a climatologic-hydrologic interfacing setting

Climate change scenarios have been developed for the study area, after statistically analyzing about 30 simulations with 11 different regional climate models (RCMs) and more than 20 simulations with global climate models (GCMs). Simulation results have been processed for the variables rainfall, temperature and potential evapotranspiration (ETo) till 2100. The climate model simulations assess future climate trends based on the prediction of future greenhouse gas (GHG) emissions made by the Intergovernmental Panel for Climate Change (IPCC). They are based on four SRES scenarios (A1B, A2, B1 and B2). The regional climate model simulations with the A1B, A2 and B2 regional scenarios were obtained from the European PRUDENCE and ENSEMBLES projects, where these RCMs were nested in a rather limited number of GCMs. To cover a wider range of GCMs, additional GCM runs (A1B and B1 scenarios) were extracted from the IPCC AR4 database. Consistencies with historical station based observations have been tested for historical climate conditions and for the recent climate trends (Baguis et al., 2010). To account for the high uncertainties in the future climate projections, “high”, “mean” and “low” climate change scenarios have been developed (Fig. 3). They depend on time scale, return period and season / month. For rainfall, both changes in rainfall intensity and rainstorm frequency have been considered. The three climate change scenarios are defined as high, mean and low based on the expected hydrological impacts. The definition is not dependent on the projected rainfalls alone. Rather it is based on the combined effect of rainfall and ETo; in other words, the variables are combined to generate an impact which can then be classified as high, mean and low. The high scenario projects a future with wet winters and dry summers while the low scenario projects a future with dry winters and dry summers. The risk associated with flooding thus is higher in the high scenario than the low scenario which is critical for low flows. It is notable that the mean scenario represents mean conditions and is not the best future guess. Simulation of the three scenarios in the hydrological impact models allows assessing the range of uncertainty in future climate projections due to differences between the IPCC SRES GHG emission scenarios, and due to differences between the more than 50 climate model simulation runs considered.

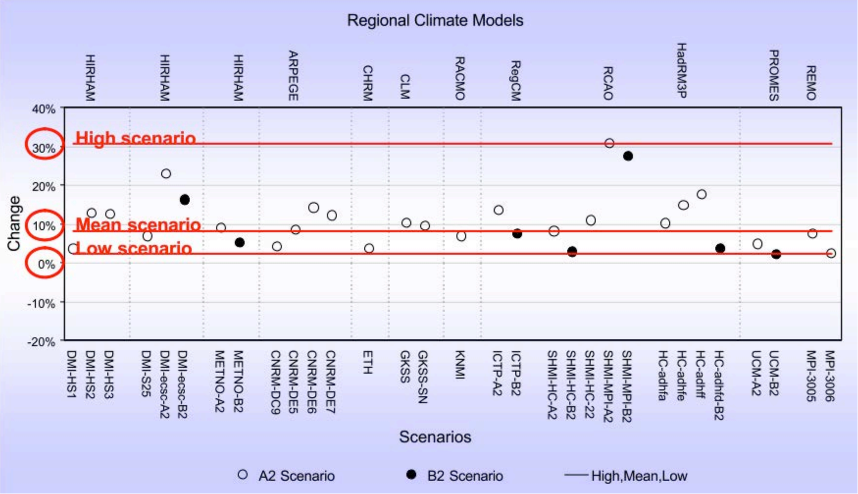


Fig. 3 Relative change in daily precipitation depth for different RCM runs (figure for winter season, and PRUDENCE RCM simulations).

The climate scenarios were developed through involvement of climatologists and statistical hydrologists (Ntegeka et al., 2008). A number of methodological issues were addressed including:

- Consistency check between RCM/GCM results and station based observations for historical periods: Which physical climatology factors explain the statistical inconsistencies? Do we need to reject or accept statistically outlying climate model results?
- Statistical downscaling: transformation of changes at daily and spatial grid scales (RCM/GCM scales) to changes at hourly and point scales (hydrological impact analysis): several existing methods; additional uncertainties involved in the statistical downscaling process to be taken into account!?
- Poor accuracy of precipitation results from RCM/GCM simulations: direct use of precipitation results versus weather typing and temperature based methods?
- Dependency between changes in precipitation, temperature and ETo when defining high, mean and low climate scenarios (maintaining physical consistency between variables).

Many research questions, however, still remain open. Two are mentioned below:

- Differences between SRES scenarios versus new IPCC scenarios referred to as “Representative Concentration Pathways (RCPs)” (including the effect of mitigation; Moss et al., 2008).
- Role of multidecadal climate oscillations (Ntegeka & Willems, 2008; Willems &

Yiou, 2010) in the evaluation of historical trends and in the results of climate models.

Impact of climate change on the flow regimes along floodplains and on aquatic and floodplains biodiversity, in a hydrologic-ecologic interfacing setting

The climate change scenarios for rainfall, temperature and ETo have been propagated to changes in the variables describing the flow regime along floodplains (inundation depth, inundation duration, spatial inundation extent, season of inundation) and the physico-chemical water quality. These are indeed identified as variables of relevance for ecological investigations. They are used to determine compatibility/vulnerability of flood characteristics with the vegetation types. In order to propagate the climate change scenarios to changes in flow regimes along floodplains of the Grote Nete basin, use is made of hydrological, hydrodynamic and physico-chemical water quality models. The basin's rainfall-runoff response is quantified after comparison of three models: a detailed physically-based and spatially distributed model implemented in the software MIKE-SHE (DHI, 2008), and two types of lumped conceptual models (NAM, VHM). The three types of models predicted similar changes in the basin's rainfall-runoff, where the impacts generally tend towards wetter winters and drier summers. The runoff peaks systematically increase and decrease depending on the scenario showing high uncertainty and can reach increases up to +35% (for hourly peak flows). Low flows decrease severely in all cases (from 20% to 70% decrease in lowest daily summer flows). The VHM lumped conceptual rainfall-runoff results were used as input in a full hydrodynamic models for the main rivers in the basin, implemented in the MIKE11 river modelling software (Fig. 1). Floodplains were implemented in this MIKE11 model based on the quasi-2D approach, schematizing each floodplain with a network of fictitious river branches and spills (Willems et al., 2002). The branches represent the topographical depressions along the floodplain (implemented in the main flow direction), where the cross-sections cover the entire depression volume. The branches are connected by spills, which represent local topographical elevations along the floodplain (including the dikes between the river and the floodplain, or other local elevations such as roads, railways, hills, …). Using GIS and a Digital Elevation Model, flood maps are created which provide results on the depth, spatial extent and duration of the simulated inundations.

Two types of hydrodynamic simulations are conducted: simulation of historical flood events (all events in a continuous long-term simulation for the full period with available input data since 1986, with hourly time step), and simulation of synthetic events for given return periods (composite hydrograph method; return periods between 1 and 100 years). Hydrological model results are validated based on river flow observations at 5 locations along the basin (Fig. 1) and groundwater well observations (only for MIKE-SHE). Hydrodynamic simulation results are verified based on water level observations at the flow gauging stations and historical flood maps (maximum extent of the inundations). Fig. 4 shows an example of such verification for the flood event of 09-1998 (largest event in the simulated period considered; estimated return period of about 100 years).

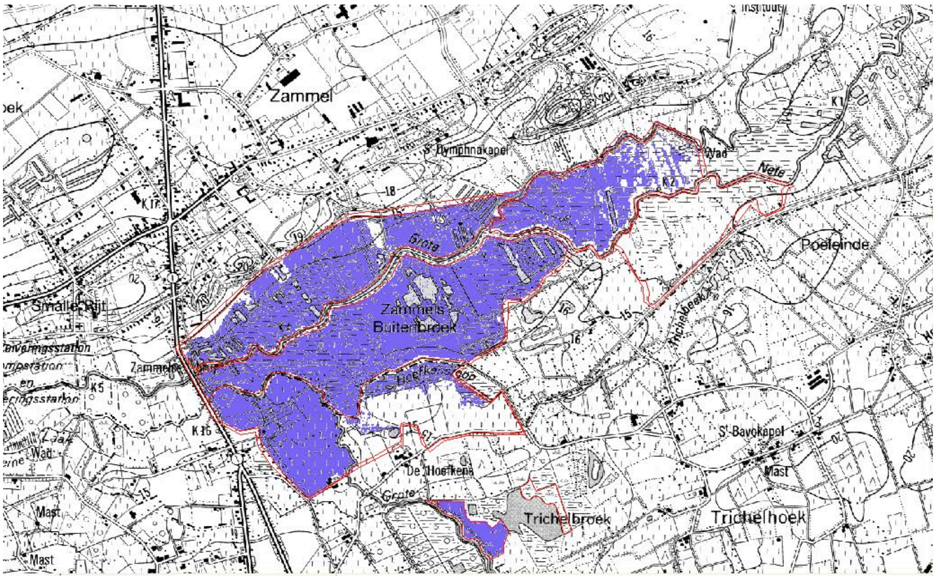


Fig. 4 Flood map for 09-1998: Comparison of the observed maximum spatial flood extent (red polylines) with the model result (blue areas).

The MIKE11 hydrodynamic model of the main rivers and floodplains is extended with a physico-chemical water quality model after implementation of domestic, industrial and agricultural pollution sources. The pollution sources are transferred to river and floodplain water quality concentrations after consideration of advection, dispersion and the most important transformation processes for water quality variables describing components of the oxygen cycle (DO, BOD, temperature), nitrogen cycle (NO3-N, NH4-N) and phosphorous cycle. The input of nutrients on the floodplains during floods is crucial in determining the vulnerability/compatibility of habitats to floods.

To enable propagation of the changes in the flow regime and the (chemical) water quality on the riparian aquatic and floodplain ecosystems (including the impacts of climate change), a database is developed on the sensitivity of riparian communities to flood regimes and water quality. Also a method is developed to evaluate the cumulative impact of flood regimes and water quality over longer time periods (considering the recovery time and carrying capacity) on biodiversity for modelled scenarios. The starting point is a thorough study of current abiotic factors for vegetation development and the relation with the biological values. The effects of altered flood regimes and altered water quality indeed depend on site specific abiotic conditions. An ecotope classification map (called Biological Valuation Map: BVM) and a vegetation inventory are used to illustrate the value of each vegetation type in the potential flood zones. The BVM ecotype classification is largely defined on the basis of vegetation, land use and small landscape elements. For the case of the Grote Nete, the BVM and vegetation inventory (Fig. 5) almost cover the entire alluvium, which allows us to assess the biological value of each vegetation type in details. Each vegetation community is represented within a database that relates to various parameters of flood-tolerance. The flood-tolerance is substantiated by an extensive literature study on the effects of flooding on the vegetation. The critical parameters (flood characteristics) that are derived from that study are then used to determine the compatibility/vulnerability of flood characteristics with the vegetation types. The information is aggregated in knowledge tables that indicate the critical tolerance for the different flood characteristics (GIS analysis) (Staes et al., 2010). In this study, 68 vegetation communities and 48 flood types are considered (Fig. 6), where Table 1 illustrates that the flood types are defined based on the flood season, flood frequency, inundation duration and depth.

During the case-study based impact modelling, a number of hydrological-ecological interfacing problems were identified, which need further focus and research. They include:

- There are high uncertainties in the estimation of the flood duration (no direct observation data available).
- Flood hazard mapping based on synthetic events, as traditionally done in flood risk management studies, is only feasible for large return periods (above the flow threshold considered in the statistical extreme value analysis). Contradictory to flood risk studies, estimation of flow regimes for small return periods (frequent events) is – for ecological impact studies – as important (or more important) as for high return periods. Estimation of frequent events requires continuous long-term simulations to be carried out, which is feasible for the lumped conceptual rainfall-runoff models but unfeasible for the full hydrodynamic river and floodplain models because of the long computational times of the latter models. In the case-study, this problem has been solved after calibration of a simplified conceptual model to the full hydrodynamic model and run the long-term simulation in the simplified model.
- So far in the case study, longer term (accumulated) domestic, industrial and agricultural pollution impacts were considered. The Grote Nete is also largely influenced by short-duration pollution impacts from Combined Sewer Overflows (CSOs). The catchment of the Grote Nete is intersected by 7 wastewater treatment zones, of which 5 drain to wastewater treatment zones (WWTPs) outside the catchment’s boundaries. These water movements largely affect the flow regimes, mainly during the (extreme) high and low flow periods. Moreover, climate change will have different impacts on river catchment rainfall-runoff and sewer outflows, because of the different response times of river and sewer systems and the different flood seasons (mainly summer of sewer systems; most severe river floods in winter). Due to climate change in the case study, CSO frequencies tend to increase, as well as the CSO pollutant concentrations due to prolonged dry weather periods during which sediments accumulate (higher storm flush for same CSO discharge). Also in the river, same CSO discharge can lead to a higher impact, due to prolonged low flow periods in summer and increased eutrophication.
- The effect of macrophyte growth in the rivers should be taken into account (also their important effects on the river hydrodynamics during low flow periods). During past decades, the growth of macrophytes largely increased along the lowland rivers due to the increased waste water treatment efficiency for suspended solids (improved light penetration and allowed re-establishment of macrophytes). The present excessive macrophyte growth during low flows increases the hydraulic head, decreases valley drainage and results in more stable and higher groundwater levels. The reduced drainage also increases denitrification because the area of water saturated soils increases as the residence time of both surface and groundwater increases. The water retention has positive effects on water quality if droughts persist, but may cause problems for harvesting crops in the valleys and may cause floods during summer storms. These feedback mechanisms need further study.
- Next to sewer systems and wastewater treatment, many other non-climatic factors determine the hydrological state (increase in paved areas, embankment of rivers, …) and ecological state (pollution, floodplain drainage, …) of the rivers and floodplains. Determining the impact of climate change on already heavily impacted

ecosystems is rather ambivalent and in that case natural reference situations could be of use.

- Knowledge concerning the relative importance of the processes affecting vegetation during floods (ecohydrological functioning of the floodplains) is rather limited and needs to be extended.
- Filling in the scores in the knowledge table that indicate the critical tolerance of different vegetation types on flood characteristics remains partly based on expert judgment.
- The use of the BVM to evaluate the ecological effects of floods has limitations, given that different types of nature exist in one BVM code or different BVM codes cover one vegetation type. By using nature types and including all types of nature which potentially can occur in a floodplain we hope to offer managers an instrument to formulate more detailed statements for areas where this is necessary.

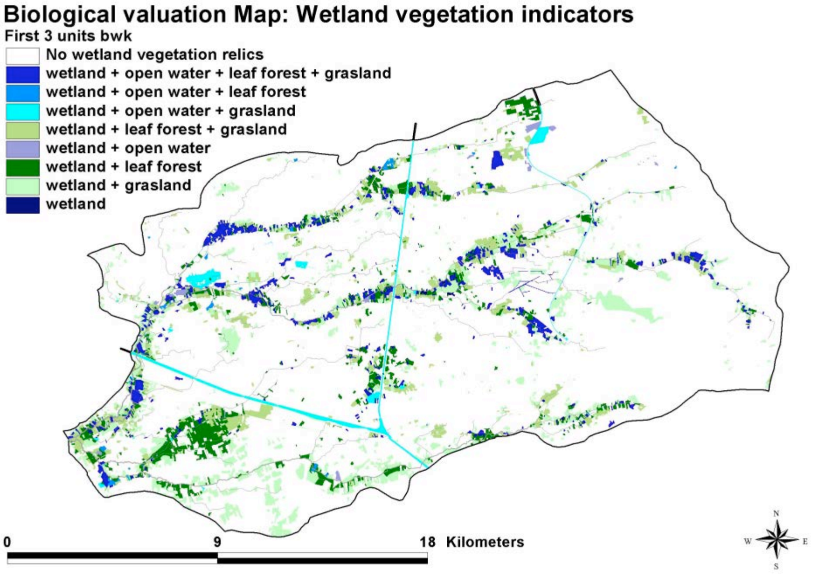
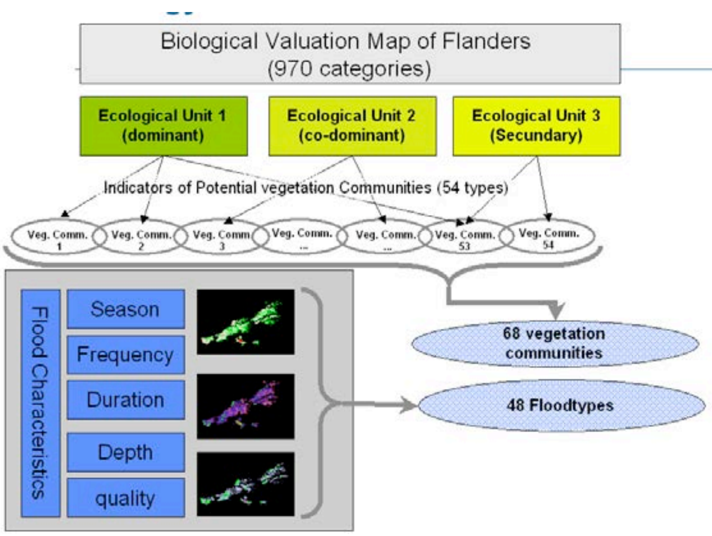


Fig. 5 Biological Valuation Map: water dependent terrestrial and aquatic ecosystems (for the dominant vegetation community = first unit of the BVM; top figure); wetland and open water indicators (bottom figure).



Flood-type	Period	Frequency	Duration days	Depth (cm)
0	W	> 25	<14	<20
1	W	> 25	<14	20 < x < 50
2	W	> 25	<14	>50
3	W	> 25	>14	<20
4	W	> 25	>14	20 < x < 50
5	W	> 25	>14	>50
6	W	5 < x < 25	<14	<20
7	W	5 < x < 25	<14	20 < x < 50
8	W	5 < x < 25	<14	>50
9	W	5 < x < 25	>14	<20
10	W	5 < x < 25	>14	20 < x < 50
11	W	5 < x < 25	>14	>50
12	W	1 < x < 5	<14	<20
13	W	1 < x < 5	<14	20 < x < 50
14	W	1 < x < 5	<14	>50
15	W	1 < x < 5	>14	<20
16	W	1 < x < 5	>14	20 < x < 50
17	W	1 < x < 5	>14	>50
18	W	< 1	<14	<20
19	W	< 1	<14	20 < x < 50
20	W	< 1	<14	>50
21	W	< 1	>14	<20
22	W	< 1	>14	20 < x < 50
23	W	< 1	>14	>50
24	Z	> 25	<14	<20
25	Z	> 25	<14	20 < x < 50
26	Z	> 25	<14	>50
27	Z	> 25	>14	<20
28	Z	> 25	>14	20 < x < 50
29	Z	> 25	>14	>50
30	Z	5 < x < 25	<14	<20
31	Z	5 < x < 25	<14	20 < x < 50
32	Z	5 < x < 25	<14	>50
33	Z	5 < x < 25	>14	<20
34	Z	5 < x < 25	>14	20 < x < 50
35	Z	5 < x < 25	>14	>50
36	Z	1 < x < 5	<14	<20
37	Z	1 < x < 5	<14	20 < x < 50
38	Z	1 < x < 5	<14	>50
39	Z	1 < x < 5	>14	<20
40	Z	1 < x < 5	>14	20 < x < 50
41	Z	1 < x < 5	>14	>50
42	Z	< 1	<14	<20
43	Z	< 1	<14	20 < x < 50
44	Z	< 1	<14	>50
45	Z	< 1	>14	<20
46	Z	< 1	>14	20 < x < 50
47	Z	< 1	>14	>50

Fig. 6 Methodology for Biological Valuation Map based vegetation type classification, and flood type classification (diagram left) based on flood period (W: winter, Z: summer), flood frequency (return period in years), inundation duration and depth (table right).

Integration of technical outcomes in basin management policy and plans

The climate change impact results at the end need to be transferred to information of use for direct implementation in basin management policy and plans. They also should support adaptation strategies.

In the project, discussions are being held with water managers and decision makers on their needs/wishes addressing hydrological-ecological climate change impacts as well as the high uncertainties in the climate change projections and impact estimates. Also bilateral contacts are sought with land management and nature development agencies and nature and landscape ngo's. To focus the science-policy interfacing, the results from the technical working groups with specific focus on the Grote Nete basin are used as real-case application. The estimated implications for this basin allow us discussing deeply what are the needs for adaptation measures? How to protect the valuable biodiversity of the floodplains in the subbasin? The social and economic implications of such measures are also discussed, as well as the needs for other policy-relevant research (looking at impacts for which little studies are available regarding Belgium, and/or interfacing between climate change community and sector specialists is insufficient).

The interfacing between the climate change technical impact calculations and the management sector plays in two directions. The development of a credible long term vision for water management and nature development is indeed desirable for the evaluation of climate scenarios, while that vision might depend on the climate change impact projections. Apart from these projections, there are currently many ongoing and planned initiatives that will influence the water system. There is an added value to compare the climate change response of the current situation to the long term vision. In that way, the long term vision can be evaluated (to check whether this vision is climate proof) and adapted (including adaptation objectives and adaptive management strategies).

Based on the assessment of the future changes in flood characteristics and water quality, adaptation measures can be designed. One of the possible adaptation measures is the reconnection of formerly embanked areas or wetland restoration. These will provide opportunities for climate change impact mitigation, and – at the same time – restoration of valuable floodplain ecosystems. Fig. 7 shows minimal and maximal restoration scenarios that were developed for the study basin for both groundwater dependent wetlands (GFW) and river stage influences wetlands (SFW). The GFW scenarios are determined by selecting the wettest parts of the basin, reduced by the requirement that land use should be reversible without excessive costs. The SFW scenarios are restricted to the river alluvium. Evaluation of the practical achievability of these SFW scenarios is based on scores obtained from the height difference with the nearest stream and the distance to the stream. The approach results in a suitability map for both types of scenarios (Fig. 7).

Other adaptation measures next to floodplain-wetland restoration include river rehabilitation, nature development, installation of fish migration passages, etc. It is important to note that there is a clear synergy between nature development and water management. Integration of both in designing adaptation measures will lead to a more natural water system and more robust nature development with ecosystem functions such as water conservation, groundwater replenishment, flood storage and nutrient retention.

Quantification of the effects of the adaptation measures requires additional hydrological-ecological interfacing issues to be considered. River and wetland restoration, for instance, requires the hydrological model to be of physically detailed and spatially distributed nature (e.g. type MIKE-SHE; Staes et al., 2009). For computational time reasons and in order to enable statistical results to be obtained, that model needs to be complemented with an equivalent simplified (e.g. conceptual) model. It is clear from the above that hydrological-ecological climate change impact and adaptive studies requires software developments and extension of modelling techniques. There is a need for high performant open source modelling, where the modelling needs can be implemented in a more flexible manner. Development from scratch is almost impossible and current commercial modelling packages do not show this flexibility.

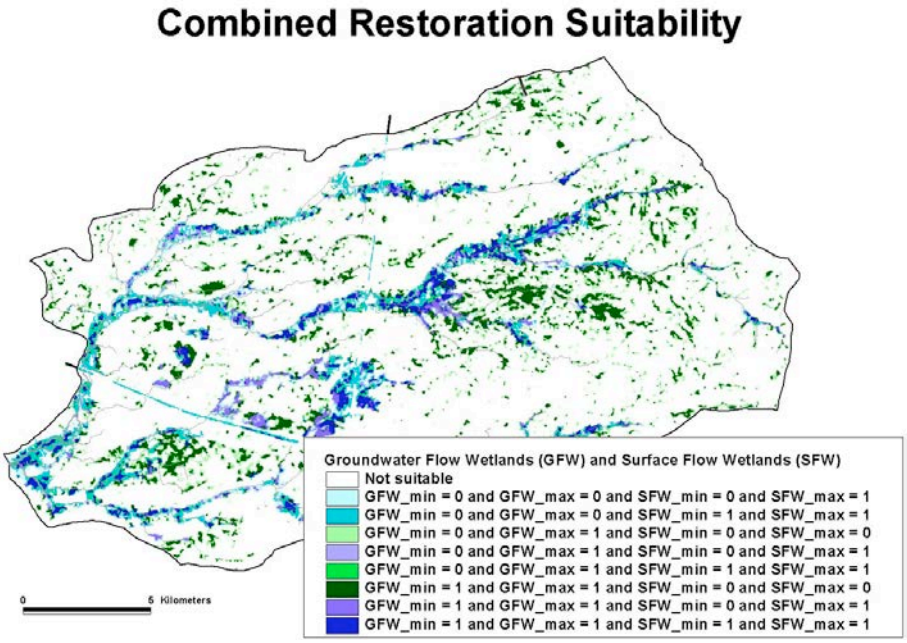


Fig. 7 Combined restoration suitability for groundwater dependent wetlands (GFW) and river stage influenced wetlands (SFW).

DISCUSSION AND CONCLUSIONS

In order to improve the decision making regarding the impact of climate change on aquatic and floodplain ecosystems, interdisciplinary linkages and feedback mechanisms have to be considered between disciplines of:

- Climate change
- Urban hydrology and sewage infrastructure
- Catchment hydrology and river hydraulics: quantity and timing of water flows
- Chemical water quality
- Macrophyte species composition and growth
- Statistical characteristics of flooding episodes
- Biodiversity values
- Etc.

Also the interrelations and communication with water managers and policy makers play a very important role. These interrelations and feedback mechanisms have long been underestimated and to a certain extent these mechanisms also have played a lesser role in the past. Taking the Grote Nete basin in Belgium as example, some interrelations have been identified and documented. We also have exemplified which variables are needed for interdisciplinary research, as well as the practical limitations and potential consequences.

One of the practical problems is that knowledge of future climate change is largely incomplete, particularly at the regional scale and with regard to extremes. Also the need to rely on socio-economic projections contributes to uncertainty, although the broad features of climate change in the country are being increasingly confirmed. Thus, part of the information needed by decision makers consists in descriptions of the uncertainty in future impacts of potential choices. Here a close collaboration between all partners is needed with focus on the translation of the scientific results into an easy and applied language for the policy makers.

The project also has identified a whole range of knowledge gaps and challenges, often of a fundamental nature, based in the interfacing between climatology and hydrology and between hydrology and ecology, which require additional and strong interdisciplinary research oriented towards adopting these interrelations.

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